PART 1: The Block Time Interpretation of Einstein's General Relativity:

An Argument In Favor of Block Time as the Correct Interpretation, With Respect to the Nature of Time, of Albert Einstein's Theory of Relativity

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Introduction

In this paper, the author will argue for both a minor statement and a major statement. The minor statement recognizes that the existence of competing interpretations of Quantum Mechanics (QM) is well known – key examples being the Copenhagen interpretation and the Many Worlds interpretation. Partly because of their being identified as interpretations and explicitly labeled as such, these have been deeply explored and actively discussed, both individually and in comparison. The minor statement further argues that General Relativity (GR) also has distinct interpretations with respect to the ontological nature of time; and that it would be beneficial to formally identify and explicitly label them as interpretations. In this way, they too can be well-known, deeply explored, and actively discussed. Though interpretations are speculative and essentially philosophical, if a particular set of interpretations (one each for QM and GR) are true, then any true breakthrough physics must be consistent with them. The odd implications made by these theories, which have prompted their interpretations, can then be seen as clues, as guiding lights, which may lead to new insights, and ultimately, to new physics.

The remainder of this paper will concern the major statement – that among existing, identifiable interpretations of GR with respect to the nature of time, there is only one that is actually *supported* by GR. It is known as "Block Time," or the "Block Universe" and it is essentially a relativistic take on the ancient philosophical concept of eternalism. It is different from, and should not be confused with, another interpretation known by its proponents as the "*Growing* Block Universe theory of time." Both of these, and two others, will be identified and contrasted in support of the Block Time interpretation.

Note that "GR" is used exclusively throughout this discussion to refer to the totality of Einstein's Theory of Relativity; even though most of these concepts can be described with, and first appear in, his Special Relativity. This is justifiable here since Special Relativity is entirely contained within GR as a special case, and is accurate to the extent that gravity can be ignored.

Shut Up and Calculate (Relativistic Presentism)

The first interpretation of GR to be presented will be referred to here as the Shut Up and Calculate interpretation; it is the philosophical concept of presentism as viewed through a relativistic lens. It says: time is not a dimension in any literal sense, it is only treated *somewhat similarly* (emphasis here because it is true) to a spacial dimension in the math. Time flows just as we perceive it to, with the past disappearing from existence and the future more or less undetermined and also not yet existent. In any case, musings about the philosophical implications of GR are a waste of time, and all that matters is learning and applying the equations.

This is a perfectly adequate interpretation for engineers; but in terms of understanding any deeper physical implications, it has a problem. Consider a constant spacetime interval between two comoving events, where the events are the tip and tail of a spaceship traveling at a constant relativistic speed compared to an outside observer. As we see from the Lorentz transformations and the geometry thereof, an observer in the spaceship's inertial frame of reference sees the entire interval as spacelike – as the length of their spaceship. The outside observer sees the interval at an angle, so to speak, such that it features both spacelike and timelike vector components. The outside observer experiences the timelike component as extra time occurring between clock ticks on the spaceship – time dilation – and the spacelike component as shorter than that observed on the spaceship – length contraction.

If a portion of a spacetime interval can be observed as either spacial length or as the passage of time by different observers, then space and time must in some fundamental way be of the same substance. This is why we have the concept of a spacetime continuum. (Maybe take a moment to seriously ponder – about how a portion of one observer's *length* can be perceived by another observer as *the passage of time*; this is real, and at least as "weird" as QM!) The degree to which time is of the same substance as space implies, at least weakly, that moments in the past and future exist in a physical direction that is merely impossible to point in.

Moving Through Time

The second interpretation of GR will be referred to here as the Moving Through Time interpretation. It says: a reasonably macro-scale object such as an orange is a three dimensional construction, physically moving along a time axis. As the orange moves through time, it evolves as expected (perhaps it rots) and remains as a three dimensional object. The past disappears from existence in the course of this evolution, and the future is more or less undetermined and also not yet existent. This movement along a time axis in spacetime accommodates the use of the Lorentz transformations, and is therefore implicitly held to account for relativistic weirdness (time dilation and length contraction).

This interpretation has even more problems. First, if the time evolution of an object is basically independent of spacetime, then Moving Through Time becomes somewhat redundant. That is, the orange could just as well remain stationary in spacetime, while still evolving in time by rotting. It arguably might explain some relativistic weirdness, but at the cost of greatly complicating time evolution.

Also, If the orange is moving in the time direction, then this implies some velocity vector, a component vector representing only this timelike motion. The question then becomes, what are the *units* on the magnitude of this vector? If the distance traveled is in the time direction, then its units must be seconds; but seconds per what? Perhaps seconds per second (seriously?) or maybe seconds per… ubersecond? We are taught that dimensional analysis – in the sense of attaching units to variables in order to check the validity of algebra performed – is a useful tool. This must be true even where GR is concerned.

This issue is addressed in what is probably the most compelling defense of Moving Through Time in a YouTube video. It is provided by Dr. Sabine Hossenfelder, of the Frankfurt Institute for Advanced Studies, in her video Do We Travel Through Time at the Speed of Light. To her credit, she first recognizes that naively formulating a “speed in time” might “end up with the arguably correct but rather lame insight that we travel through time at one second per second.”

For a better derivation, she ultimately displays a spacetime interval in the form: $\Delta s = \sqrt{-(\Delta x)^2 -(\Delta y)^2 -(\Delta z)^2 +(c\Delta t)^2}$. Before this, though, she recognizes that “space and time have different units,” so the constant c is put in front of Δt to convert its units and allow addition of the terms. She also notes that a constant could be put in front of each of the spacial terms instead, but "by convention we put it in front of the time coordinate."

She divides both sides by the "time difference," which on the left hand side is Δt, and inside the radical (square root) symbol on the right hand side becomes $(\Delta t)^2$. Then she cancels all of the spacial terms on the grounds that "relative to yourself, you do not move through space." This yields $\Delta s / \Delta t = c$, ostensively quantifying the speed at which one moves "into the timelike direction." Her algebra is, of course, sound enough; but it is none the less fair to remain skeptical about the interpretation.

For one thing, at the instant that she makes the decision to divide both sides by Δt, $\Delta s / \Delta t$ is forced to look somewhat like a velocity. Stating afterwards that this is to be interpreted as a real velocity can be construed as a bit of a tautology. Significantly though, note that in Dr. Hossenfelder’s formulation, Δs carries units of distance (as it does). As such, $\Delta s / \Delta t = c$ agrees on both sides in terms of units, making this argument appear to satisfy dimensional analysis.

Dr. Don Lincoln of Fermilab, in his YouTube video Why Can’t You Go Faster Than Light, explains how it works in the general case for an outside observer, where the spacial terms can not be canceled out. In this case, the constant “moving through spacetime at a single speed, the speed of light” is portioned out between spacelike and timelike vector components, relative to the inertial frame of the outside observer. As such, Dr. Hossenfelder’s treatment of the special case of one's own calculation of one's movement through spacetime is still valid in the general case for all observer's calculations of one's movement through spacetime.

So, the spacetime interval is in units of length, and lengths are *inherently static*, not moving or flowing. Meanwhile, Dr. Hossenfelder's formulation of the interval is exclusively referring to a distance on one's own proper time axis; as such, this fully timelike spacetime interval could just as well be labeled with units of time. This would return $\Delta s / \Delta t$ to being logically equivalent to time divided by time, with units of seconds per second (which is “arguably” nonsense), or at least leaving it with units that are entirely ill-defined. Also, the equation $\Delta s / \Delta t = c$ does *not* satisfy dimensional analysis if the fully timelike spacetime interval is interpreted as having units of time.

If we use the general case, *and* we choose to put the conversion constant in front of the spacial terms, we get: $\Delta s = \sqrt{-(c^{-1}\Delta x)^2 -(c^{-1}\Delta y)^2 -(c^{-1}\Delta z)^2 +(\Delta t)^2}$. If we perform the same treatment as Dr. Hossenfelder and cancel out the spacial terms (to obtain a proper time interval), we now get $\Delta s = \Delta t$, or $\Delta s / \Delta t = 1$; which is very different from before, doesn't actually say much, and certainly does not imply any kind of velocity. Also note that when putting c with the spacial terms, the resulting spacetime interval ends up with units of time (which is to be expected), so we are back to seconds per second. An ad hoc way to fix seconds-per-second might be to claim it somehow as a dimensionless number; but those, like lengths, tend to be *static*, used as ratios as opposed to rates.

When formulated as a “four-velocity,” this construct represents a very strange velocity indeed, in that its magnitude is immutably constant for all observers (basically c). Only the direction of the vector is variable, and *then* only in response to varying inertial frames of reference and not, strictly speaking, to any acceleration.

Four-velocity takes into account the different proper time axes of different observers; but only as relative vector angles, not as unique dimensions. So, if Moving Through Time is allowed, there must still be an extra layer of time evolution (as described above) in order to allow oranges to rot – and to allow for physically moving across an interval which *already* includes a time component, albeit expressed in spacial units. As such, four-velocity can be a velocity in name only, unless measured in *(seconds, meters) / ubersecond*. It is best interpreted as a math tool useful in Lorentz transformation calculations, instead of as an ontologically real velocity through spacetime; and would work as well with a different name.

And there's more! Possibly the biggest problem with the Moving Through Time interpretation involves relativistic simultaneity. Say observer 1 calculates events H and J as occurring simultaneously, with event K happening later, but observer 2 calculates event H as occurring alone followed by J and K occurring simultaneously. If J is in the past along with H as seen by observer 1, then they must both have disappeared from existence by the time observer 2 sees event K occurring. No, the only way observer 2 can see K happen alongside J is if J's existence is *persistent*, independent of any individual observer's clock.

This simultaneity problem can be framed alternately by considering the direction, now, of the supposed timelike velocity vector from above. Every object would move through time in a direction determined by its inertial frame's proper time axis; but that direction will be at an angle, so to speak, to the direction in which an observer in another frame is Moving Through Time. Even worse, all frames will disagree with all others about *everybody's* direction of movement. Which time axis has supremacy for resolving any spacetime traffic conflicts? It says right in the name, *Relativity*, that no time axis has supremacy.

Block Time

We now get to the Block Time interpretation of GR. The essence of this perspective has had several other names over the years such as "Eternalism," "the B Theory of Time," and the "Block Universe;" and it is sometimes summarized by stating that "time is tenseless." It says: a reasonably macro-scale object such as an orange is not a three dimensional construct, but it is in a very real way its entire four dimensional world line, existing simultaneously, or "eternally", at every moment in its past, present, and future. Note that "world tube" may be more descriptive for a macro object… the spherical cross-sections of a four dimensional tube can even approximate a cow very well. The ends of this world tube would be frayed in a sense, representing the accretion and dispersion of the object's constituent materials, during its synthesis and its disintegration (perhaps it rots), respectively.

A single moment in time is only definable relative to a particular inertial frame of reference, as a three-dimensional "plane" of simultaneity normal to the frame's proper time axis. This concept of a plane of simultaneity comes directly from GR, and has been eloquently referred to by one YouTuber as a "now slice."

The Block Time interpretation asserts that each now slice is a particular subset of events selected from the global set of events in an eternal spacetime. Because all events exist persistently, relativistic simultaneity becomes trivially explainable by simply accepting Lorentz transformation as a description of different cross sections of actual physical structures; that is, by taking the mathematics of GR literally. Furthermore, persistence of any observer's now slice implies the persistence and non-uniqueness of all now slices, a temporal expansion of the Copernican principle.

Time evolution is explained by slight differences in an object's configuration between eternal now slices, as is consistent with a progression of cross sections taken of continuous, curved world tubes. To be clear, time is certainly *not* an illusion, as evidenced by the fact that it appears as an independent variable in many, many highly predictive equations. It just doesn't flow.

What is not explained by Block Time is our subjective experience of time as flowing, which is likely a feature of our own mysterious consciousness, as opposed to a feature of the mechanics. This subjective experience is the (sometimes implicit) basis of many philosophical arguments against eternalism in general. In the opinion of the author: now that we have GR, this is analogous to the fact that some airplane crashes are found to be the result of "controlled flight into terrain" – where the pilot fatally trusts his or her own wrong perceptions about the aircraft's position and orientation, instead of trusting their contrary, but correct, instruments.

Since we live our entire subjective lives experiencing the illusory flow of time, we have no choice but to act and speak as though the flow is real. This condition describes a "time-bound perspective," which can be differentiated from an "eternal perspective." These perspectives have distinctly different features, but they are equally real and are only different points of view on the eternal block universe.

Of course, Block Time has its own big problem also. If all future events already exist in eternal spacetime, then the philosophical concept of predeterminism must hold true. This is a problem for Block Time because of the phenomenon known in QM as the measurement problem, where there is an abrupt change in the equation used when a quanta is measured or "observed" (which has a more constrained meaning in QM than in ordinary language). In this, the quanta goes from being described by a set of probabilities (basically) regarding all of its possible physical states – a wave function – to being described by a single state from among those possibilities – an eigenstate. A quanta moves, so to speak, as a probabilistic wave function, yet we only ever measure it to be in a singular eigenstate. There is *strong* experimental and theoretical evidence to suggest that this stochastic selection occurs only at the instant of measurement. This demands (clearly) that the future is in no way predetermined. The author's proposed reconciliation of this GR/ QM conflict is the subject of the companion paper to this one, entitled PART 2: The Permutations Conjecture.

Growing Block Universe

The final interpretation of GR discussed here will be referred to as the Growing Block Universe interpretation, and it includes QM enhancements. It says: the Block Time interpretation holds, but only for moments in the past. An extant and continuously advancing present, in which stochastic quantum events occur, lays down persistent trails in the Growing Block Universe as it goes. The future remains more or less undetermined and also not yet existent. This interpretation retains a common sense notion that the past is fixed in time, the present exists but is constantly changing, and the future is uncertain.

At first glance, Growing Block Universe has the same problem with relativistic simultaneity described above for Moving Through Time. Observers in different inertial frames of reference will disagree on the location and orientation of the "now" front (i.e. the advancing plane of simultaneity), and in some cases disagree over whether some events are in the past or the future. Dr. Matt O'Dowd of PBS Space Time (and the City University of New York) does an in depth investigation into both Block Time and Growing Block Universe in his YouTube videos Do the Past and Future Exist, and Is the Future Predetermined By Quantum Mechanics.

The measurement problem is the very reason that there are multiple interpretations of QM, and the specifics of how Growing Block Universe addresses it depends on which interpretation is chosen. In all cases, though, the QM concept of superposition – the state in which a quanta is described by all of the possibilities in its wave function – is invoked in order to allow both an uncertain future and relativistic simultaneity. In the words of Dr. O'Dowd, "all this stuff outside our past light cone, and even unobserved aspects of the world within that cone, exist in a state of indeterminacy until observed." This mitigates the problem with relativistic simultaneity; but possibly only by shifting the problem onto QM, where it must still be decided which observer has supremacy for determining the "real" observed eigenstate(s). Dr. O'Dowd suggests that a feature of at least one interpretation of QM – decoherence – might resolve this problem as well.

In the marginally comprehending opinion of the author, the Growing Block Universe interpretation is plausible and worthy of exploration; however it might also be described as the worst of both worlds. By begrudgingly admitting Block Time in the past, and taking on all of its dimensional baggage, it removes only about one half of the problem with relativistic simultaneity – by making portions of possible spacetime intervals fixed in time for everyone. The other half of the problem, found in the advancing now front and the immediate future, is still as problematic as with Moving Through Time, but now with a quantum flavor. Significantly, Growing Block Universe forces a re-definition of the measurement problem, with the new feature that QM must take on the role of establishing the direction of causality by one or another means. On the other hand, the rigorous attempt to merge GR concepts of causality with those of QM is compelling. Likewise, the use of decoherence is compelling as always.

Conclusion

No doubt the Internets can provide more and possibly better arguments against the Block Time interpretation, or in favor of one of its rivals. Great! Let's all talk about *interpretations* of Einstein's General Theory of Relativity with respect to the real nature of time.

Meanwhile, visualizing Block Time can lead to some fascinating extrapolations. For example, the totality of all of the world lines, for the entire mass-energy content of the universe, forms a sparse, fully-interconnected web-like structure (at both galactic and quantum scales) – as opposed to the “block” referred to in its name. Also consider the case of a universe with a closed (spherical) spacial geometry; that is, with a positive curvature of space. If we assume Block Time, and also that the curvature of space is non-intrinsic, then instead of being visualized as a stack of planes of simultaneity, the time dimension would be more properly visualized as radial to a set of concentric spheres of simultaneity, so to speak. This would have implications for Hubble expansion, since that could be interpreted as the result of world lines being, in a sense, aligned radially from the center of the concentric spheres (which is the beginning of time).

Block Time might be the most literal and explanative way to interpret GR. However, it is admittedly counter-intuitive and will likely always suffer a bias against it when compared to arguments which appeal to the subjective experience of time. Physicists, though, like good pilots, are trained to "fly by instruments." There is a possibility that doing so in this case could lead to a much more complete understanding of natural mechanics.